Collective flow at intermediate energies

J. Łukasik and W. Trautmann for the INDRA and ALADiN Collaborations

Gesellschaft für Schwerionenforschung mbH, D-64291 Darmstadt, Germany

Abstract

We present results of a flow analysis for the set of reactions of ^{124,129}Xe projectiles and ^{112,124}Sn targets at incident energies 100 and 150 A MeV studied with the INDRA detector at GSI. The dependence on centrality and on p_t of the directed and elliptic flow are determined for isotopically selected reaction products with $Z \leq 3$. The flow parameters v_1 and v_2, in general, follow expected trends but isotopic effects are small.

Key words: Nuclear reactions, multifragment emission, collective flow
PACS: 25.70.Mn, 25.70.Pq, 25.75.Ld

The high accuracy that can be achieved in the experimental determination of flow parameters from data collected with advanced 4π detection systems has recently been demonstrated in a combined analysis of INDRA and FOPI data [1]. Excitation functions for directed and elliptic flow were constructed for ^{197}Au + ^{197}Au reactions over a large range of incident energies extending from 40 A MeV to several A GeV using the data measured at SIS by the two collaborations [2,3] but also data taken at the AGS [4,5].

In this analysis, corrections were applied for the reaction plane dispersion using the random sub-event method, assuming a non-isotropic Gaussian distribution of sub-Q-vectors and taking into account the correlation between sub-events [1,6], but also for other experimental effects such as losses due to the finite detector acceptance and multi-hit events. The agreement reached for the INDRA and FOPI data in the overlap region 90 to 150 A MeV covered by the two data sets is within 5% to at most 10%.

We believe that data with this level of precision can be useful for the investigation of presumably small isotopic effects related to the symmetry term in the nuclear equation of state, with the aim to reduce its present uncertainty at densities beyond the saturation density [7,8]. For example, the recent analyses of the isospin diffusion data measured at Michigan State University [9] have shown that the result deduced for the stiffness of the symmetry energy is very sensitive to the chosen interaction and to the type of nucleon-nucleon cross sections adopted for the transport model description [8,9]. Flow

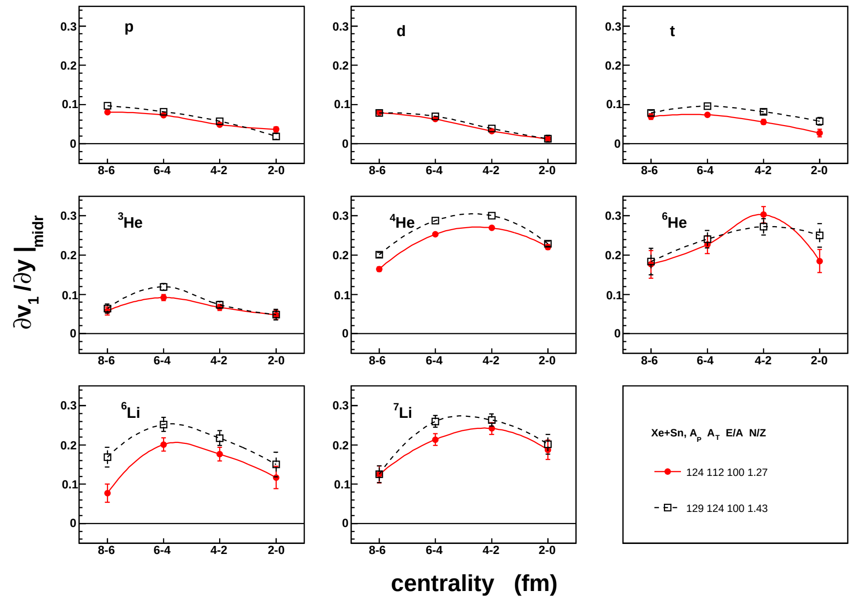

Fig. 1. Slopes of directed flow $\partial v_1/\partial y$ at mid-rapidity for eight reaction products with $Z \leq 3$ integrated over $p_t/m > 0.1$ as a function of centrality for the most neutron rich (open squares, black) and the most neutron poor (dots, red) reaction systems at 100 A MeV.

observables are generally sensitive to these ingredients and thus provide opportunities for testing the overall consistency of the model description. Additional sensitivity to the isospin-dependent part of the interaction can be expected from data for reaction systems with varying isotopic compositions as well as for analyses for pairs of reaction products with opposite isospin (mirror nuclei).

The data used for the present analysis were obtained by the INDRA and ALADIN collaborations in measurements using ^{124,129}Xe projectiles of 100 and 150 MeV per nucleon delivered by the heavy-ion synchrotron SIS at GSI. Isotopically enriched targets of ^{112,124}Sn were used and data were taken for all four combinations of projectile and target at 100 A MeV and for the two projectiles and the ^{124}Sn target at 150 A MeV.

The INDRA multi-detector provides good acceptance and mass resolution at and near midrapidity at the present range of bombarding energies. The flow parameters v_1 and v_2, appearing as coefficients of the Fourier decomposition

$$\frac{dN}{d(\phi - \phi_R)} = \frac{N_0}{2\pi}(1 + 2\sum_{n\geq 1} v_n \cos n(\phi - \phi_R)) \tag{1}$$

of the azimuthal yield distributions, were obtained from the corresponding fits and determined as a function of impact parameter, rapidity y and transverse momentum p_t. Examples of the obtained results are shown for two, the most neutron-rich and the most neutron poor, of the four systems studied at 100 A MeV in Figs. 1 and 2. The dependence of the directed flow (slope $\partial v_1/\partial y$ at mid-rapidity) and of the elliptic flow (v_2 at mid-rapidity) are shown for eight reaction products with $Z \leq 3$, selected with the condition $p_t/m > 0.1$.

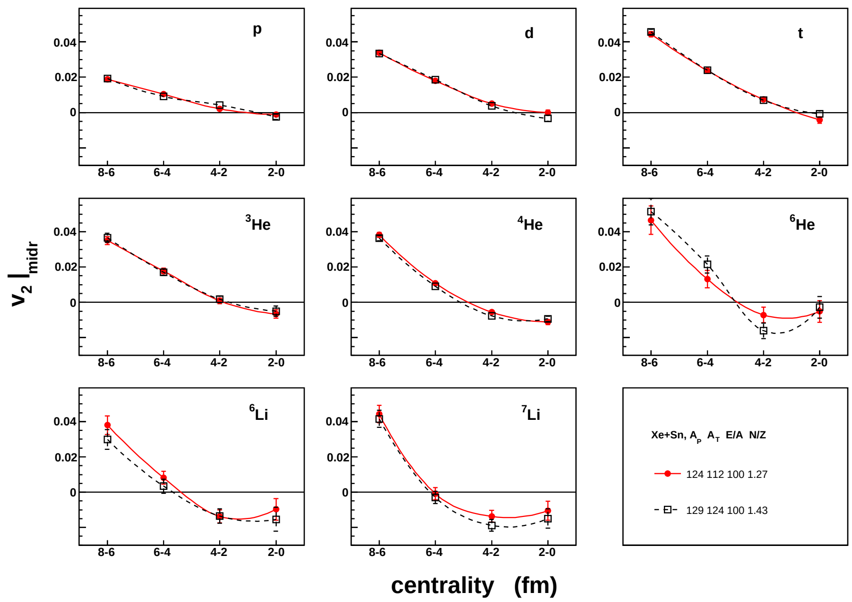

Fig. 2. Elliptic flow parameter v_2 at mid-rapidity for eight reaction products with $Z \leq 3$ integrated over $p_t/m > 0.1$ as a function of centrality for the most neutron rich (open squares, black) and the most neutron poor (dots, red) reaction systems at 100 A MeV.

The overall behaviour follows the expectations, in particular the dependence on the fragment mass and the impact parameter (see figures) as well as that on the bombarding energy and on p_t (not shown). A possibly isotopic effect is observed for the directed flow which is consistently larger for the more neutron-rich (but with 17 more nucleons also more massive) system. It is not obvious that a different behaviour of mirror nuclei can be ascertained, and isotopic effects are practically absent in the elliptic flow (Fig. 2).

The displayed data are uncorrected which is sufficient to permit the direct visualization of the magnitude of the isotopic effects. For a comparison with theory, the above mentioned corrections will have to be applied or, alternatively, simulated events will have to be passed through a filter routine.

References

[1] A. Andronic et al., Eur. Phys. J. A **30** (2006) 31, and in *Dynamics and Thermodynamics with Nuclear Degrees of Freedom* ed. by Ph. Chomaz et al., Springer, Berlin Heidelberg New York, 2006.
[2] J. Łukasik et al., Phys. Lett. B **608** (2005) 223.
[3] A. Andronic et al., Phys. Lett. B **612** (2005) 173.
[4] C. Pinkenburg et al., Phys. Rev. Lett. **83** (1999) 1295.
[5] P. Braun-Munzinger and J. Stachel, Nucl. Phys. A **638** (1998) 3c.
[6] J. Łukasik and W. Trautmann, preprint nucl-ex/0603028 (2006).
[7] M. Di Toro, S.J. Yennello, B.-A. Li, Eur. Phys. J. A **30** (2006) 153.
[8] Lie-Wen Chen et al., preprint arXiv:0704.2340(nucl-th), (2007).
[9] M.B. Tsang et al., Phys. Rev. Lett. **92** (2004) 062701.